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CARBON RESISTOR PRESSURE GAUGE CALIBRATION AT STRESSES UP TO 1 GPa

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Abstract

Calibration of the 470-Ohm carbon resistor gauge is desired in the low stress region up to 1 GPa. A split-Hopkinson pressure bar, drop tower apparatus, gas pressure chamber, and gas gun have been used to perform the calibration experiments. The gauge behavior at elevated temperature was also investigated by heating the resistors to 200°C at atmospheric pressure while observing the resistance change. The motivation for this calibration work arises from the desire to increase the number of data points in the low stress regime to better establish the accuracy and precision of the gauge. Details of the various calibration arrangements and the results are discussed and compared to calibration curves fit to previously published calibration data. It was found that in most cases, the data from this work fit the calibration curves fit to previously published data rather well.

INTRODUCTION

The carbon resistor gauge has previously been studied by numerous researchers [1-10] for several different initial resistance values. This gauge is a simple carbon composition resistor that can be used as a pressure gauge with little or no modification. The equipment needed is a power supply to provide a small amount of constant current or alternatively a Wheatstone bridge could be used. Because of ease of use, ability to measure pressures up to 3 GPa, and survivability in harsh environments, it can be used in cases where no other gauge would survive. Because the gauge is manufactured to be a resistor and not a pressure gauge, an empirical calibration is required.

Recent experiments at Lawrence Livermore National Laboratory (LLNL) [11,12] have incorporated the 470 Ω carbon resistor gauge in energetic materials. Typically, measurements ranging from 0.1 to 3 GPa are made. The goal of this work is to characterize the calibration of the 470 Ω carbon resistor gauge at low pressures (<1 GPa) using a static gas pressure chamber (argon environment), a split-Hopkinson bar, a drop tower apparatus and a gas gun. Because some experiments require heating of the experimental assembly, the behavior of the resistor at ambient pressure and at elevated initial temperatures was also investigated.

EXPERIMENTAL PROCEDURE

The resistors used in this work were standard 1/8 W, 470 Ω carbon composition resistors made by Allen-Bradley Corporation. The nominal dimensions of the resistor are 1.7 mm diameter and 4 mm long, with wire leads extending from each end of the cylinder. The details of the procedure for each calibration as well as the results for that calibration, are in the respective sections below. During each experiment the constant current power supply for the carbon resistor gauges remained on at all times and supplied ~16 mA of constant current through the 470 Ω resistor gauges. This simplifies the experiment by requiring only the digitizers to be triggered when the event occurs, to record gauge response.

Static Gas Pressure Chamber

The static gas pressure calibrations of the carbon resistor gauge were performed in a pressure chamber that is usually used to measure burn rates of enegetic materials at elevated temperatures and pressures. Further details of the apparatus are included elsewhere [13]. Figure 1 outlines a general schematic of the assembly used. The chamber has the capability to be pressurized to 0.4 GPa with a gas (in this case argon). As indicated in Figure 1, a calibrated Kistler model 6213B quartz gauge [14] is located at one end of the chamber to measure the pressure in the chamber and the carbon resistor gauge array (5 gauges) is located at the other end. During the loading in the experiment, the output from the gauges are continuously scanned on a Keithly digital voltmeter and saved on a computer.

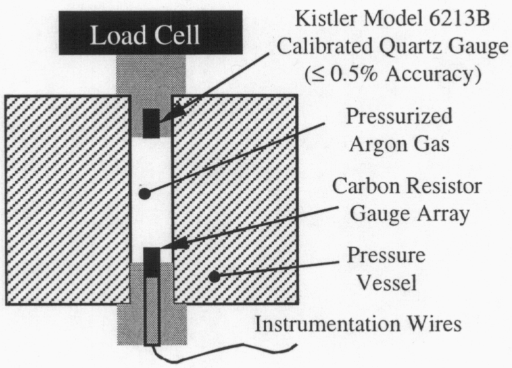

FIGURE 1. Schematic outlining the gas pressure chamber assembly.

Split-Hopkinson Bar

Calibration experiments were performed using a split-Hopkinson bar apparatus. Details of the operation of the split-Hopkinson pressure bar can be found in associated references [15,16]. Figure 2 (a) shows a schematic of the apparatus which consists of a striker bar impacting an incident bar that is adjacent to the sample and backed by a transmitter bar. The bars are operated in the elastic regime and strain gauges are placed on the input and transmitter bars to measure the strains. The input and transmitted stresses can be calculated using the elastic modulus of the bar material. Bars made from 9.5 mm diameter 6061-T6 aluminum were used in these calibration experiments. Figure 2 (b) outlines the schematic carbon resistor gauge arrangement that consisted of two sample halves that are 7.6 mm diameter by 2.5 mm and 5 mm thick respectively. The carbon resistor gauge was placed in grooves in the larger sample half, and then the sample was joined together with Dow Corning 3145 RTV sealant [17]. For the analysis, the sample stress was calculated by using the transmitted stress in the transmitter bar (calculated from the peak strain) multiplied by the ratio of the aluminum bar diameter to the final Teflon sample (with embedded gauge) diameter. A Tektronix TDS 784D oscilloscope was used to measure the carbon resistor gauge output during the experiment.

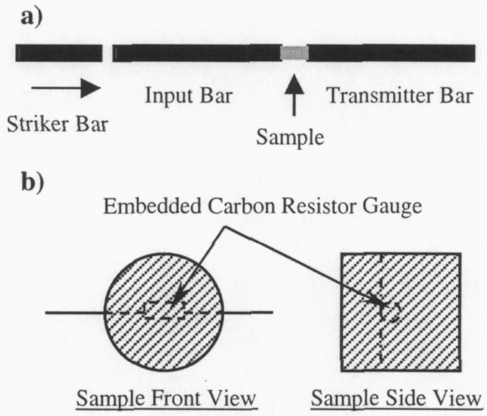

FIGURE 2. Schematic showing (a) split-Hopkinson bar arrangement and (b) general illustration of carbon resistor gauge (~4mm long by 1.7 mm diameter) inside Teflon sample.

Drop Weight Apparatus

A commercially available drop weight apparatus, model 913B02 Hydraulic Impulse Calibrator, obtained from PCB, Piezotronics [18] was used. Figure 3 shows a schematic of the apparatus with a 4 kg drop weight dropped from different heights (0.1, 0.41, 0.71, 1.18, and 1.49 meters) which impacts a plunger assembly that creates hydraulic pressure in the silicone fluid (Dow 200 silicone oil, 20 centistokes viscosity [17]). The calibrated PCB Piezotronics model 136A [18] quartz reference transducer and carbon resistor pressure gauge sample were placed equal distances from the center of the fluid cell. A PCB model 443A101/443A102 dual mode amplifier was used to amplify the calibrated gauge signal and a Tektronix TDS 784D oscilloscope was used to measure the carbon resistor gauge output during the experiment. In the analysis, the peak value from the calibrated pressure gauge was correlated to the peak resistance change from the carbon resistor gauge. Both signal peaks correlated well in time.

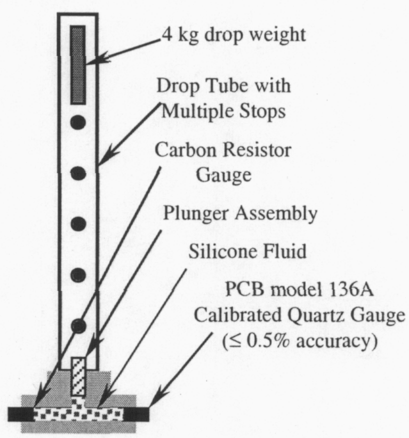

FIGURE 3. Schematic showing the drop weight carbon resistor gauge calibration set-up.

Gas Gun Experiments

Experiments were performed in a 101 mm diameter propellant driven gas gun impacting a polymethylmethacrylate (PMMA) flyer onto a PMMA target with embedded carbon resistor gauges. Figure 4 shows a schematic of the experimental configuration with gauge layout. The target plates were all 90 mm in diameter with a buffer plate thickness of 5 mm backed by 2 12.7 mm target plates. The impact velocities achieved in the two experiments were 190 and 506 m/s. An array of 3 carbon resistors recessed into machined grooves, a manganin gauge (the standard "LLNL gauge"), and a carbon foil gauge (Dynasen model C300-50-EKRTE) were inserted on each of two levels as indicated in Figure 4. The foil gauges were sandwiched between layers of Teflon insulation, and Shell-Epon 815 epoxy was used to hold the assembly levels together. A polynomial fit to the pressure versus particle velocity PMMA data taken from Barker and Hollenbach [19] was used to calculate the pressure achieved in the impact. Using this data to relate the particle velocity to pressure, the impact velocity was the only parameter needed to calculate the pressure (the particle velocity equals one-half the impact velocity in a symmetric impact).

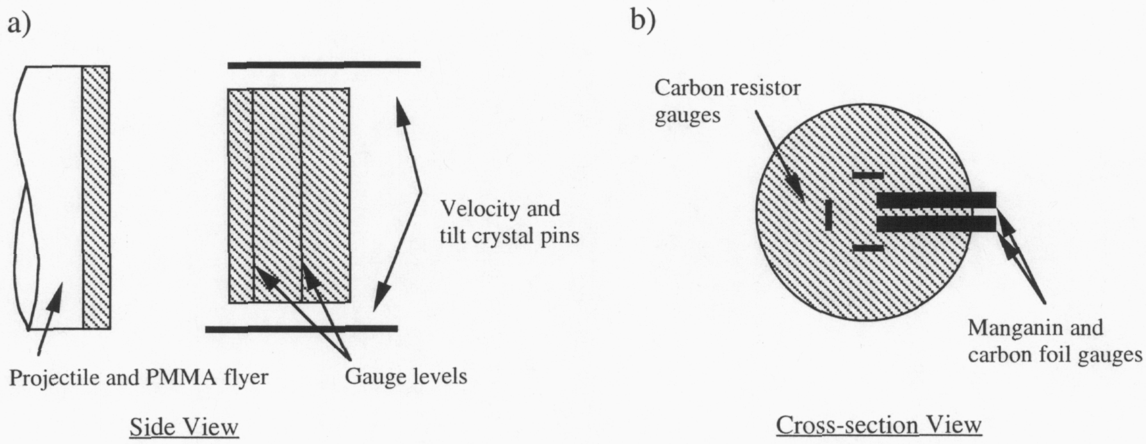

FIGURE 4. Schematic of the gauge placement for the gas gun experiments with (a) side and (b) cross-section views.

Investigation of Heating at Atmospheric Pressure

The effect of heating at atmospheric pressure on the carbon resistor pressure gauge was investigated by placing an array of resistors in an oven and heating them in air to 160°C. During the heating the carbon resistor gauge resistance was continuously scanned on a Keithley digital ohmmeter and output to a computer that recorded the resistance value of the gauges and thermocouple voltage.

DISCUSSION

A summary plot of the results compared with the calibration curves fit to previously published data is given in Figure 5. Two runs of the gas pressure chamber data to 0.2 and 0.4 GPa are shown as lines that represent the average value from the array of 5 resistor gauges. It was observed that there was little difference in relative resistance change between individual resistors, thus the average value was used. Note that small jogs are seen at 0.05 GPa increments where the increase in gas pressure was held constant to enable equilibration of the carbon resistor gauge.

The split-Hopkinson bar data is shown as open squares and the drop tower data is shown as open circles. It should be noted that with the drop tower data, some of the points were obtained from multiple drops on the same resistor with no observable deviation. This is an indication of the rugged nature of the carbon resistor gauge. The gas gun data points are shown with x-type symbols and represent the average of all resistors in the experiment. The calibration curves of Wilson [20] and Ginsberg and Asay [4] are also plotted as a thick solid line and a dashed line respectively.

In this summary plot (Figure 5), it can be seen that the gas gun experiment data (pressures above 0.3 GPa) fits that of Ginsberg and Asay [4], while the remaining data fits the calibration curve of Wilson [20]. The gas pressure chamber data falls slightly below the Wilson [20] calibration curve, which is expected due to the static nature of the loading. Both the drop tower and split-Hopkinson data also follow the Wilson [20] calibration curve reasonably well, but are slightly above the curve. For the gas gun experiments, both experiments are slightly above the curve of Ginsberg and Asay [4] but still fit the curve rather well.

In general, it appears that fitting a new calibration curve that combines the goodness of fit of both curves to the data would be desired. However, more data is needed in the range between 0.4 and 0.9 GPa and to complete this fitting routine. Comparing the static data to the more dynamic data of the drop tower and gas gun data may also indicate a slight strain rate dependence, but more work would need to be done to establish this further.

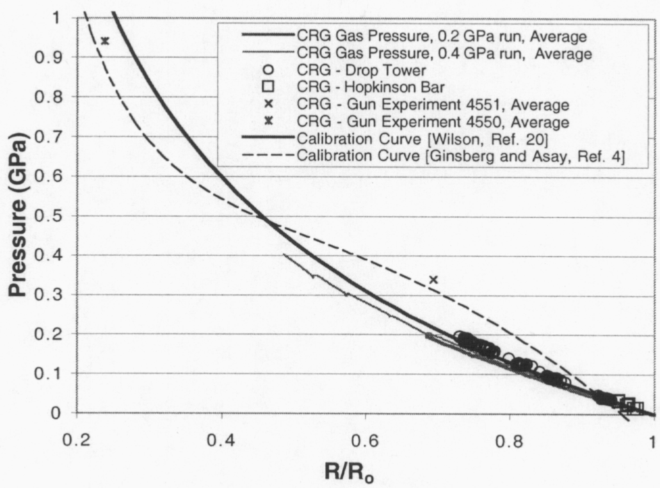

FIGURE 5. Summary plot of the carbon resistor gauge calibration compared with the calibration curve fit to previously published data.

Figure 6 displays the relationship between temperature and resistance change of the carbon resistor gauge. From this plot it can be seen that there is only a 4% change in resistance on average, and a 1.4% difference among groups when gauges are heated from ambient to 160°C.

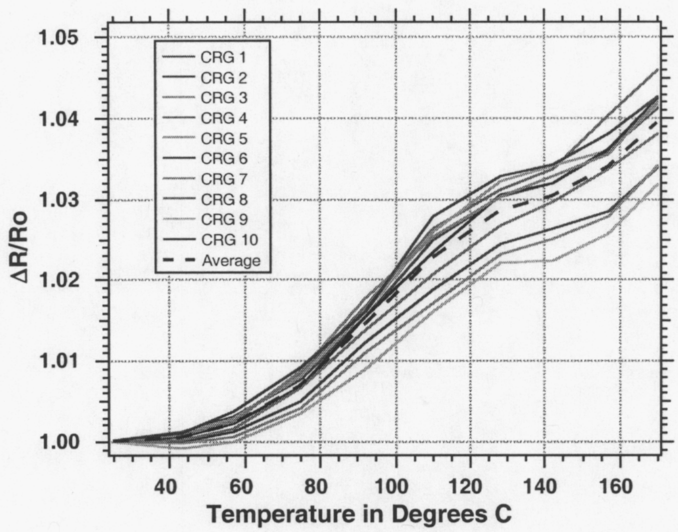

FIGURE 6. Change in resistance as a function of temperature (at atmospheric pressure) for 10 carbon resistor gauges. Note the dashed line is the average value.

SUMMARY AND FUTURE WORK

Calibration experiments were performed at low stresses (<1 GPa) to compare results to calibration curves fit to previously published calibration data. The new experiments used: a split-Hopkinson pressure bar, a drop tower apparatus, gas pressure chamber, and a propellant driven gas gun. The gas pressure chamber, split-Hopkinson bar, and drop tower data fit one the calibration curves well and the gas gun data fits the other calibration curve well. Resistance of the carbon resistor gauge was shown to only vary 4%, on average, when heated from ambient to 160°C at atmospheric pressure.

More gas gun experiments are in progress to extend the number of data points in this low stress regime (<1 GPa) and are also being conducted in this range at elevated temperatures (~80°C) to establish gauge behavior at this temperature. Once completed, this data can be utilized to obtain a calibration curve that offer a good fit to the entire applicable pressure range of the carbon resistor gauge. Adding the data that was used to create the previous calibration curves to the current data set to establish this new curve is also planned to ensure the most accurate fit.

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